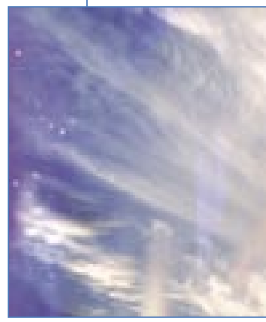


5 Integration and Synthesis

The science focus areas enable NASA to tackle the Earth system science puzzle by arranging the problem in interdisciplinary yet implementable pieces which are themselves interconnected. Earth system science requires that we also bring the pieces back together.

Global and continuous observations from space combined with a comprehensive program of modeling, analysis, and synthesis enable the Earth system science research within NASA necessary to address challenging questions and issues of contemporary interest to society while extending our fundamental understanding of planet Earth. The Earth science focus areas provide the scientific basis for Earth observations and develop and maintain the research to resolve the science questions that underpin NASA's effort. Over the next decade, NASA will contribute far better capabilities for Earth observations and for projecting variations and change in the Earth system. Table 5.1 summarizes the major outcomes focusing on prediction that NASA expects to produce. Collectively, these outcomes represent a challenging decadal goal that requires unprecedented integration and synthesis of observations and the broad array of scientific results produced by research tasks within each focus area.

Many of the projected outcomes result from combining multiple observations, coupling models, and the synthesis of scientific results. Important properties and variables, such as the carbon content of soils, are not amenable to remote sensing and are better estimated from in situ measurements, where available, incorporated into models that are otherwise constrained over large areas by remote sensing. Assimilation of satellite observations into models provides a means of diagnosing the full states of major components of the Earth system, estimating current conditions for the entire system, and forecasting or predicting change. Satellite data assimi-

Table 5.1.

Projected Outcomes		
Climate Variability and Change	How can predictions of climate variability and change be improved?	Predict near- and long-term climate change, implications for global sea level change, regional temperature, precipitation, and soil moisture. For example by 2014: • Reduce uncertainty in global sea level rise by 50%; • Enable 10-year or longer climate forecasts.
Atmospheric Composition	How will future changes in atmospheric composition affect ozone, climate, and air quality?	Predict the course of recovery of Earth's atmospheric ozone shield and assess the air quality. For example by 2014: • Predict global distribution of stratospheric and tropospheric ozone to within 25%; • Enable extension of air quality forecasts for ozone and aerosols from 24 to 72 hours.
Carbon Cycle and Ecosystems	How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?	Predict global terrestrial and oceanic biological productivity, ecosystem health, and interactions with the climate system. For example by 2014: • Project 10 to 100-year concentrations of CO_2 and CH_4 with greater than 50% improvement in confidence; • Enable ecological forecasts that project sensitivity of terrestrial and marine ecosystems.
Water and Energy Cycle	How will water and energy cycle dynamics change in the future?	Improve intermediate range forecasts for droughts and seasonal water supply; predict global scale energy storage and transport in the atmosphere. For example by 2014: • Enable seasonal precipitation forecasts at 10–100 km resolution with greater than 75% accuracy; • Balance global water and energy budgets to within 10%
Weather	How can weather forecast duration and reliability be improved?	Significantly improve short-term and severe weather forecasts for hurricanes, winter storm hazards, and other extreme weather events. For example by 2014: • Decreased hurricane landfall uncertainty from ± 100 km in 3-day forecasts; • Enable 7–10 day forecasts at 75% accuracy.
Earth Surface and Interior	How can our knowledge of Earth surface change be used to predict and mitigate natural hazards?	Predict volcanic activity within a month and estimate earthquake probabilities for selected tectonic zones. For example by 2014: • Enable 30-day volcanic eruption forecasts with greater than 50% confidence; • Estimation earthquake likelihood in North American plate boundaries with greater than 50% confidence.

lation for weather forecasting demonstrates the enormous potential of this approach.

Thus, as illustrated by figure. 5.1, NASA Earth science research is directed toward a fully coupled Earth system model constrained and driven by satellite observations. Incremental progress by coupling the models emerging from focus area research within a formal Earth system modeling framework enables important products along the path to a fully coupled model. For example, the dependence of the carbon cycle

Table 5.2a

U.S. Climate Change Science Program elements and NASA Earth science focus areas	
CCSP Research Elements	**Earth Science Focus Areas**
Atmospheric Composition	Atmospheric Composition
Climate Variability and Change	Climate Variability and Change
Global Water Cycle	Global Water and Energy Cyle
Land Use/Land Cover Change Global Carbon Cycle Ecosystems	Carbon Cycle and Ecosystems
Human Contributions and Response	
	Weather

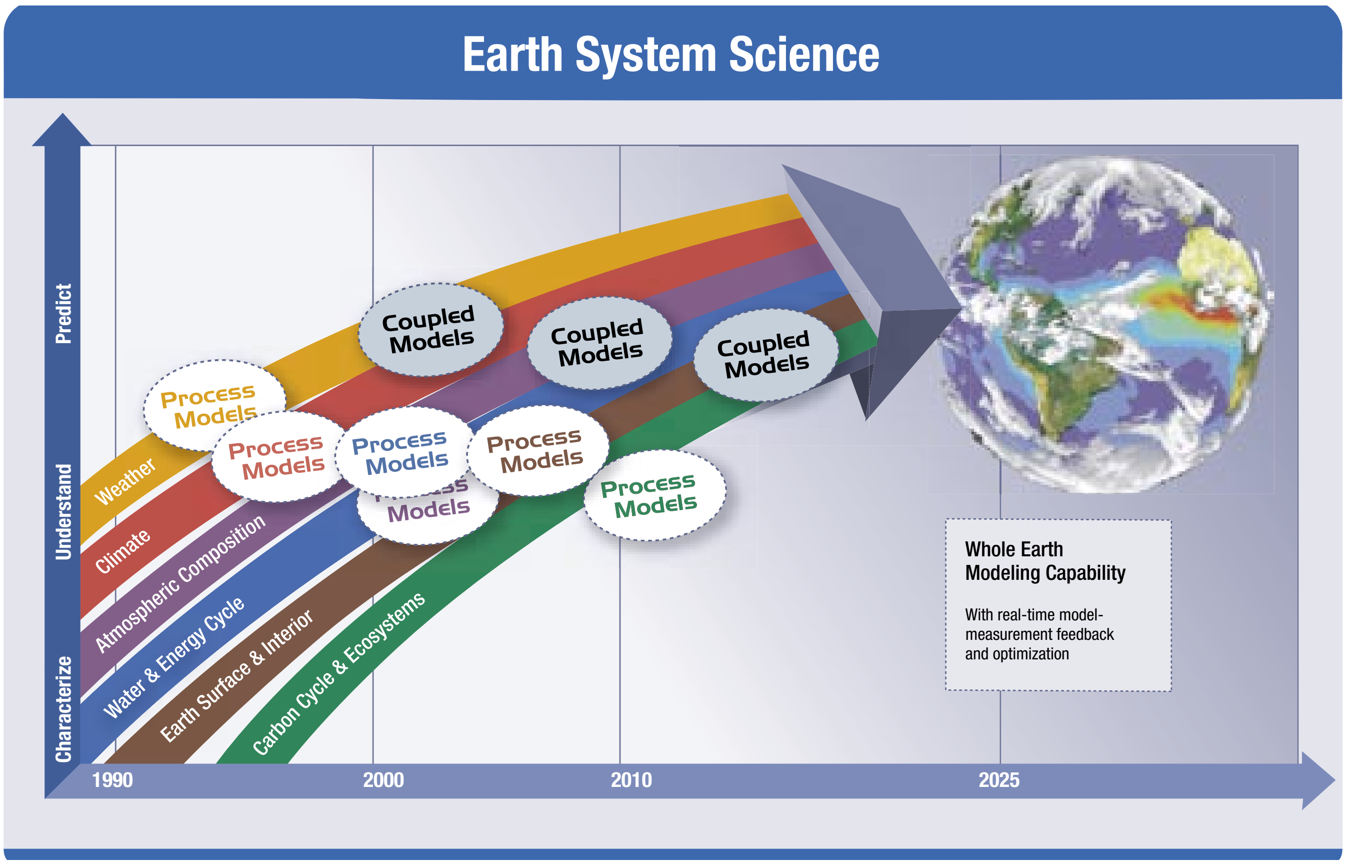
and climate systems on each other is so strong, that coupled models of these systems are being used now to provide better understanding of potential climate change due to CO_2 increase. These coupled carbon cycle and climate models will be improved further in the future by coupling to full atmospheric chemistry models in order to consider other atmospheric constituents or the shorter term influences of weather by incorporating weather phenomena.

NASA's goals in Earth science research, Earth observations, and Earth system modeling mandate coordination and collaboration with other Federal agencies. The U.S. Climate

Table 5.2b

U.S. Climate Change Science Program goals and NASA Earth science research questions	
CCSP Research Elements	**Earth Science Research Questions**
Improve knowledge of the Earth's past and present climate and environment, including its natural variability, and improve understanding of the causes of observed variability and change	How is the global Earth system changing? (Variability)
Improve quantification of the forces bringing about changes in the Earth's climate and related systems	What are the primary causes of change in the Earth system? (Forcings)
Reduce uncertainty in projections of how the Earth's climate and related systems may change in the future	How does the Earth system respond to natural and human-induced changes? (Response)
Understand the sensitivity and adaptability of different natural and managed ecosystems and human systems to climate and related global changes	What are the consequences of change in the Earth system for human civilization? (Consequences)
Explore the uses and identify the limits of evolving knowledge to manage risks and opportunities related to climate variability and change	How will the Earth system change in the future? (Prediction)

Figure 5.1



Change Science Program provides the framework for this cooperation toward resolving a suite of questions closely related to those in table 2.1, and NASA's Earth science focus areas are closely aligned with CCSP program elements (table 5.2a and b). The CCSP is committed to synthesis and assessment products, many of which will make use of Satellite observations and Earth system modeling results. Table 5.3 lists the products that NASA is directly responsible for, either in a lead or supporting role. Scientific results from all of NASA's Earth science focus areas will play in the CCSP synthesis; data products and model results aimed at decision support will be critical to producing assessment products.

Earth science research within NASA works in synergy with technology and education programs through constant interaction to introduce innovation and to continually revitalize the pool of talented scientists and engineers that will carry the program into yet unforeseen frontiers (figure. 5.2). The applied science program works to bring the wealth of observations and research results into decision support for nationally prominent topics. Companion plans describe the Education, Technology, and Applied Science Programs (figure. 1.2), taking guidance from this research plan and the Agency's overall Earth science strategy.

As figure 5.2 illustrates, the NASA Earth science program incorporates a critical cycle from research outcomes and their impacts back to the assumptions and questions underlying the research effort. New investigators and technological innovation are important drivers of this cycle. As we gain new knowledge and capabilities, new questions will replace those of today, and the current science focus areas will realign or perhaps be replaced to address new challenges. The research effort to address these questions will demand new observations, models, and analyses—the resources and tools of next generations of Earth system scientists.

Figure 5.2

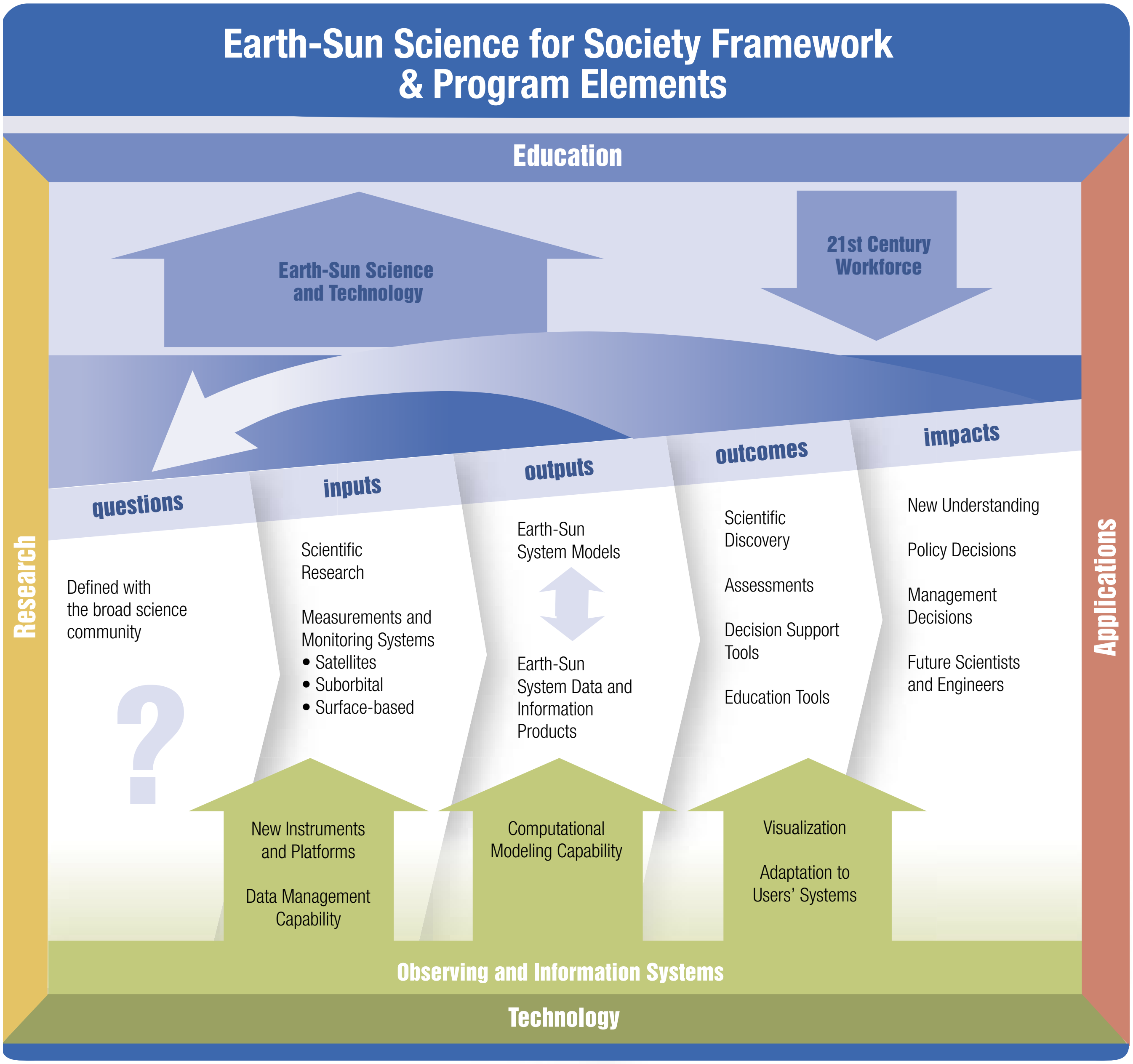

Earth-Sun Science for Society Framework & Program Elements
Education
Earth-Sun Science and Technology
21st Century Workforce
Research
Applications
questions
inputs
outputs
outcomes
impacts
Defined with the broad science community
?
Scientific Research
Measurements and Monitoring Systems
• Satellites
• Suborbital
• Surface-based
Earth-Sun System Models
Earth-Sun System Data and Information Products
Scientific Discovery
Assessments
Decision Support Tools
Education Tools
New Understanding
Policy Decisions
Management Decisions
Future Scientists and Engineers
New Instruments and Platforms
Data Management Capability
Computational Modeling Capability
Visualization
Adaptation to Users' Systems
Observing and Information Systems
Technology

Table 5.3 U.S. Climate Change Science Program synthesis and assessment products.

Reference Number	Topic	Agencies	Time Frame (From October 2003)
1.1	Temperature Trends in the Lower Atmosphere—Steps for Understanding and Reconciling Differences	NOAA (Lead); NASA, DOE, NSF	Within 2 years
1.2	Past Climate Variability and Change in the Arctic and at High Latitudes	USGS (Lead); NSF, NOAA, NASA	Within 2 years
1.3	Re-analyses of Historical Climate Data for Key Atmospheric Features—Implications for Attribution of Causes of Observed Change	NOAA, NASA(Lead); DOE	2–4 years
2.1	Updating Scenarios of Greenhouse Gas Emissions and Concentrations in Collaboration with the CCTP—Review of Integrated Scenario Development and Application	DOE (Lead); NOAA, NASA	Within 2 years
2.2	North American Carbon Budget and Implications for the Global Carbon Cycle	DOE, NOAA, NASA (Lead); USDA, USGS	Within 2 years
2.3	Aerosol Properties and Their Impacts on Climate	NOAA, NASA (Lead)	2–4 years
2.4	Trends in Emissions of Ozone-Depleting Substances, Ozone Layer Recovery, and Implications for Ultraviolet Radiation Exposure and Climate Change	NOAA, NASA (Lead)	2–4 years
3.1	Climate Models and Their Uses and Limitations, Including Sensitivity, Feedbacks, and Uncertainty Analysis	DOE (Lead); NOAA, NASA, NSF	Within 2 years
3.3	Climate Extremes Including Documentation of Current Extremes—Prospects for Improving Projections	NOAA (Lead); NASA, USGS, DOE	2–4 years
4.1	Coastal Elevation and Sensitivity to Sea Level Rise	USGS, EPA, NOAA (Lead); NASA, DOE	Within 2 years
4.3	Relationship Between Observed Ecosystem Changes and Climate Change	USGS, USDA (Lead); EPA, NOAA, NASA, NSF, USGS, DOE, USAID	2–4 years
4.4	Preliminary Review of Adaptation Options for Climate-Sensitive Ecosystems and Resources	USDA, EPA (Lead); NOAA, NASA, USGS, DOE, USAID	2–4 years
4.5	Scenario-Based Analysis of the Climatological, Environmental, Resource, Technological, and Economic Implications of Different Atmospheric Concentrations of Greenhouse Gases	CCSP (Lead); NASA, USGS, EPA, NOAA, DOE	2–4 years
4.6	State-of-the-Science of Socioeconomic and Environmental Impacts of Climate Variability	EPA (Lead); NOAA, NASA, DOE, USAID	2–4 years
4.7	Within the Transportation Sector, a Summary of Climate Change and Variability Sensitivities, Potential Impacts, and Response Options	DOT (Lead); USGS, DOE, NASA	2–4 years

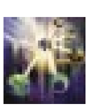


Table 5.3 Continued

Reference Number	Topic	Agencies	Time Frame (From October 2003)
5.1	Uses and Limitations of Observations, Data, Forecasts, and Other Projections in Decision Support for Selected Sectors and Regions	NASA (Lead); EPA, NOAA, USGS, DOE	Within 2 years
5.2	Best Practice Approaches for Characterizing, Communicating, and Incorporating Scientific Uncertainty in Decision Making	NASA (Lead); EPA, NOAA, USGS, DOE, NSF	Within 2 years
5.3	Decision Support Experiments and Evaluations Using Seasonal to Interannual Forecasts and Observational Data	NOAA (Lead); NASA, EPA, USGS, USAID	Within 2 years